

PERFORMANCE BASED OPERATIONS, BUILDING BLOCKS OF SESAR AND NEXTGEN. IMPLEMENTED AND USED BY ANSP'S AND AIRLINES TO IMPROVE SAFETY, EFFICIENCY, AND REDUCE EMISSIONS.

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IASSA Symposium, 23-25 November 2009

Abstract

Performance Based Operation (PBO) has opened up possibilities to operate aircraft more efficiently than done today. Benefits in terms of safety, noise, reduced fuel consumption and emissions have been identified. PBO uses the inherent capability of the aircraft to operate close to the optimum trajectory, taking into account constraints such as airspace use.

PBO consists of two parts: navigation in three dimensions and control of the fourth dimension – time. With these combined, a Performance Based Operation defines an unambiguous four dimensional trajectory (4DT). Required Navigation Performance (RNP) is used for lateral and vertical navigation, and Controlled Time of Arrival¹ (CTA) for control of along-track, ie. longitudinal, navigation. PBO, RNP, CTA and 4DT are building blocks of both SESAR and NextGen. These technologies are today available off the delivery lines and are also available for retrofit to many in-service aircraft.

The SESAR MINT² project was set up to demonstrate the combined use of CTA and RNP with current state-of-the art Airbus 321 aircraft. After 10 successful approaches during revenue flights the project will be concluded November 25th.

The next step is the use of ground systems in order to optimize the aircraft arrival sequence and increase capacity while maintaining the benefits of RNP. During the ongoing R&D project CASSIS, the Arrival Management system - EGIS AVIA MAESTRO will be improved as to be able to assign a specific approach, communicate atmospheric conditions, receive the aircraft preferred ETA and assign a CTA. MAESTRO is installed in Sweden among other countries including South Africa.

Further to SESAR, European FP7 projects such as ALICA will contribute to the improvement and implementation of technologies such as RNP and 4DT.

This paper outlines the operational concept, benefits in terms of safety, capacity, efficiency and environmental load as well as the road to realize the first steps of the PBO concept.

¹ The aircraft function to follow a CTA is known as Required Time of Arrival (RTA).

² Minimum CO₂ IN TMA

Introduction

All commercial aircraft have a business purpose and an objective to carry passengers or freight from one location to another. These locations are linked by a trajectory in space and unlike a railroad, this trajectory can be modified - and should be modified when feasible so as to adapt it to aircraft performance and environmental conditions. While much has been done by manufacturers to improve airframes, improving the possibilities of operating along an optimum trajectory has been done only on a limited scale. This is changing today when SESAR in Europe and NextGen in the US are aligning actors to move towards increased efficiency, capacity, safety and reduced cost. It is clear that this is in the interest of all actors and in the end society will benefit, starting with airport neighbors and passengers.

However, airlines today lack a vision of the efficiency that they could have, as any other Key Performance Indicator (KPI). An airline Captain or a CFO has today an understanding of actual fuel consumption, but rarely a picture about what the consumption would have been on an optimum trajectory on a given day with its environmental conditions, aircraft weight etc. A set of KPIs describing efficiency should be established for each flight so as to gain an understanding of bottlenecks and the associated potential improvements. Such a KPI would provide an objective tool for deciding where action would be most effective.

While SESAR and NextGen are important vectors forward for system development and implementation we should not neglect the dormant capability of the aircraft flying today. Aircraft have capabilities, largely unused today, especially in the approach segment, to fly closer to the optimum trajectory. These technologies include different levels of 4DT, RNP and RTA. Some ANSPs, Eurocontrol, the European Commission,

SESAR, and NextGen along with operators such as Southwest Airlines, Qantas, SAS and Novair have identified these opportunities and are working to put into place efficient near term solutions. This work has started with past and ongoing demonstration and trial activities supported by the industry, airports, ANSPs and authorities. This paper will focus on these activities and the expected benefits.

Operational concept

Both NextGen and SESAR are aligned in terms of an operational vision that includes onboard capabilities such as RNP and RTA. The most recent operational concepts demonstrated and evaluated in Australia, North America³ and Europe up until now used airborne capabilities currently available.

Alaska Airlines pioneered the use of RNP in 1996. At that time the objective was to safely circumnavigate terrain in challenging airports where conventional instrument approaches were not an option. Juneau, Alaska was the first one. Today it has moved to be a largely accepted concept with recognized benefits in terms of safety, efficiency and a reduced environmental impact. RNP uses the capability of the aircraft to follow a fully defined lateral track within defined boundary limitations. One major difference with conventional navigation is that turns are defined by a radius to fix leg (RF-leg) where the aircraft maintains a fixed distance to a waypoint. Whereas on a classic RNAV route the FMS will define the turn depending on speed etc. The trajectory will be different for different aircrafts, speeds, wind conditions etc. This variety of trajectories has to be taken into

³ North American initiatives are only briefly mentioned in this paper. One of the most important initiatives in North America today is the RNP implementation including initiatives that Southwest Airlines is pursuing in the US.

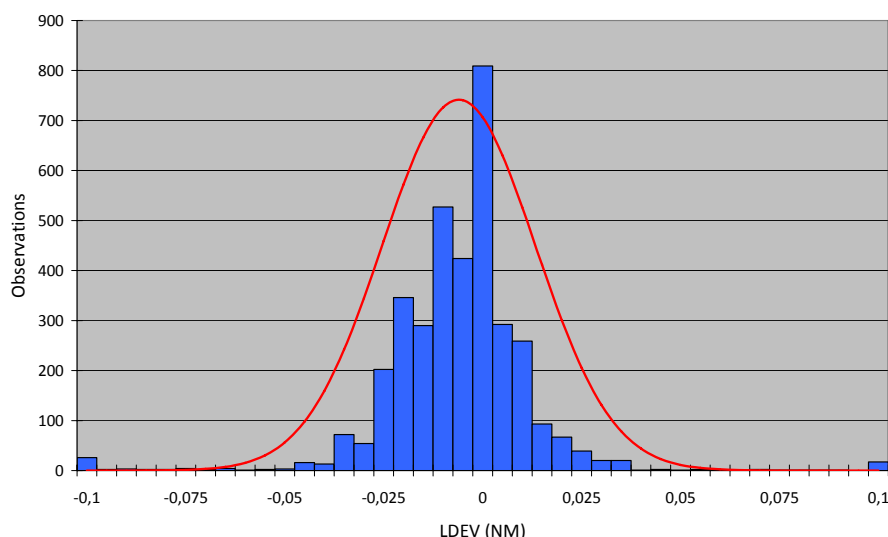


Figure 1 - Lateral Deviation below 5000ft. MINT project - 10 RNP Approaches in Stockholm Arlanda. 3625 samples. Data processed using the AVTECH PBO Analyzer™.

account in regulation and procedure design.

RNP improves navigation in two ways: the actual track is fully defined and lateral deviation, position accuracy and integrity are monitored, ie. the performance of the aircraft is monitored. This opens up possibilities to operate as a function of actual track-keeping performance, including turns which are fully defined, regardless of aircraft speed and wind.

In standard RNP approach operations, aircraft performance is ensured to be better than +/- 0.30 NM 95% of the time, ie. RNP 0.30. In RNP AR operations the requirement is down to 0.1 NM. However, in real operations the average performance is often far better than both these figures. In Figure 1 the actual performance of A321s can be seen. The observed lateral deviation is well within the required value, in this case 0.30 NM. The observed performance is here +/- 0.02 NM 95% of the time. This equals having the middle of the aircraft within a corridor 70meter/0.04 NM wide 95% of the time.

RNP provides precise lateral guidance. This enables lower minima and it opens up for a more efficient use of airspace. Further, the simple nature of the operation, compared with the complex flying required previously, improves operational safety.

Vertical navigation is ensured during RNP operations by barometric vertical guidance. Unlike a standard ILS approach there is no regulatory requirement to have a level segment prior to a glide slope intercept. This gives possibilities to conduct a complete Continuous Descent Approach on the predefined lateral track. This will be done from cruise altitude down to a Decision Altitude (DA) of 250 ft AGL⁴.

The onboard Flight Management System (FMS) is capable to calculate a Continuous Descent Approach. This will be done using forecasted winds and temperatures. When these are communicated to the FMS the aircraft will leave the cruise altitude, so as to fly the calculated optimum idle continuous descent, down to the runway threshold.

The planned trajectory, whether using RNP or not, is known to the aircraft FMS. It is a precise definition in time and space of the path the aircraft intends to follow. This information has so far been shared by few on-board systems and not at all by most external users such as Air Traffic

⁴ There are regulatory plans to bring the minimum DA in RNP operations down to 200 ft AGL. SESAR has also plans to develop new transition rules as to enable a transition from RNP to ILS (or MLS or GLS). To enable a CDA this transition must be done continuously.

Control (ATC). However, the information about the 4DT, or Intent data, is valuable information. From an ATM perspective the 4DT as computed by the FMS provides the best possible prediction available. To be able to share this information the Airlines Electronic Engineering Committee (AEEC) industry standards group has defined standards on how to extract and downlink the FMS intent data⁵. Other regulatory-support groups such as RTCA/Eurocae are in the progress of defining the standards for how to exchange these data between ATC and the aircraft

As a first project NUP2+ introduced the use of 4DT communication in Sweden. Today MINT and CASSIS will follow, building on this work.

During descent, an A320 FMS uses five forecasted winds. A good level of reliability of this information is required in order to obtain an optimum vertical profile and a high level of accuracy of the predicted flight path - 4DT, including Estimated Time of Arrival (ETA). The wind forecasts can be manually inserted in the FMS or automatically uplinked via ACARS VDL-2 datalink. This functionality is being used by some airlines. However, in many cases forecasts are old or of poor quality.

AVTECH has developed the Aventus NowCast™ system that tailors wind uplinks using either or both of the following sources:

- WAFTAGE from UK Metrological Office. A forecasted wind grid in time and space that provides a high quality forecast around the world.
- AMDAR. A system providing wind reports from many aircraft.

Using a preliminary 4DT⁶ sent by the aircraft, the Aventus NowCast system calculates the winds on the intended trajectory. Thereafter, the tool optimizes the selection of winds so as to uplink the

winds of greatest importance. The result is an onboard 4DT of high quality with an accurate ETA.

Temperatures can also be uplinked using the same system.

Once an optimal trajectory is constructed laterally, vertically and longitudinally⁷ the objective is to provide an ATM environment that will enable the trajectory to be followed without interruptions. While SESAR and NextGen will provide solutions for entire trajectories, gate-to-gate, the recent projects in Europe, Australia and North America focus on the approach. Inefficiencies for classic approaches are important, and applying PBO technologies provides solutions. However, while classic radar vectors provide flexibility, an optimum trajectory requires planning. The solution is the use of CTA in order to control flow.

The limiting resource in ATM is either airspace or airport capacity. The optimum use of these resources is achieved by minimizing time and distances to the regulatory values. Taking the example of a high capacity ILS, regardless what kind of operation is in use; only landing or landing and take off, there is an optimum flow of incoming aircraft that will maximize capacity. Traditionally a flow is put into place by controllers using radar vectors. Depending on controller skill the flow is close to optimum resulting in, if needed, a runway capacity that is maximized. Unfortunately this is often obtained at a cost in inefficiencies and emissions

The difference with an optimum trajectory with a continuous descent is that it starts when the aircraft leaves its cruise altitude some 30 min before landing. Planning is thereby required and the first step is to share the preferred intended trajectory and make it available to controllers. An improved Arrival Manager (AMAN) system is the solution

⁵ ARINC702A-1/3. AEEC is an activity hosted by ARINC Inc.

⁶ On Airbus aircraft standard FMS progress and position reports are sent and the 4DT is estimated with an algorithm developed by Airbus and AVTECH in the Aurora project.

⁷ The optimal longitudinal trajectory is defined either as a function of the FMS Cost Index or as a function of a time constraint. Cost Index 0 will result in max specific range, ie. minimum fuel consumption per NM.

to handle this information and provide support to the controller. Visibility of the flow is given as well as a tool to communicate early Standard Terminal Arrival Route (STAR) and approach information.

4DT including ETA is communicated by the aircraft to the AMAN. The 4DT and ETA has an uncertainty that will depend on aircraft performance as well as the quality of forecasted winds and temperatures⁸. If the controller accepts the uncertainty he will let the aircraft fly as intended and the ETA will evolve if the aircraft encounters winds or temperatures that are different from what was predicted. The 4DT will be updated and communicated and the evolving ETA will be monitored by the controller through the AMAN system. If the variation of ETA is not acceptable given the impact on other users, such as if the runway capacity is a scarce commodity, a Controlled Time of Arrival (CTA) can be assigned.

The CTA can be set equal to ETA or it can differ within the possibilities of the aircraft. The span of possible CTA is the control authority and will be communicated from the aircraft⁹. Operating using a CTA, becoming an RTA once in the aircraft, the aircraft will adapt speed to meet the RTA. If encountered winds and temperatures are different from forecast this will result in a trajectory that is close to but not the optimum trajectory. The loss in efficiency is here the cost for a precise arrival time. It should be noted that precise forecasts and an optimum selection of wind and temperature points will reduce this cost.

The AMAN helps the controller to optimize the use of runway or airspace. The point where CTA is set can either be the runway threshold or any point before. The control should be done for the commodity that is the most scarce; airspace or runway.

⁸ In future operations, this uncertainty could be computed by the FMS.

⁹ RTA Control Authority is defined in ARINC AEEC standards.

The vision is to reach a runway capacity of 60 movement per hour with interleaving take offs and landings. Runways today operate typically at 30-45 movements per hour. The best used European runway today is London Gatwick with a declared capacity of 50 movements per hour.

Using CTA, given that airspeeds are different, a slow aircraft might not be able to follow fast aircraft in order to meet a minimum time separation at entry point or runway threshold. The pragmatic near term vision is here to provide multiple RNP Approaches with a merging point close to the runway. An AMAN would assign CTA as to plan for a conflict free trajectory for all aircraft. The optimization goal for an AMAN would be to define an overall optimum in the given ATM environment¹⁰.

Projects today

Since RNP started in Alaska in 1996, companies such as Naverus, Quovadis and Jeppesen has helped many operators in challenging environments. Realizing the benefits in terms of efficiency and environment other operators have followed. Qantas and Airservices Australia started to operate RNP to get closer to an optimum trajectory and reduce fuel costs and environmental impacts.

The NUP2+ program introduced 4DT communication and put into place a first AMAN using this information. AURORA followed using the same concept. Both projects demonstrated ETA and RTA performance. The CASSIS project is currently running and is further exploring the possibilities to use CTA to control flow. However, RNP was not used to

¹⁰ An ADS-B ASAS solution is also a possibility and would provide a solution to maintain minimum time spacing between aircraft. However, it is clear that if a fast aircraft will reduce speed in order to follow a slow aircraft the faster aircraft will leave the optimum longitudinal trajectory. In addition an arrival optimization will need to be carried out, at the point where ASAS starts.

provide the lateral trajectory for any of these European projects.

MINT, a SESAR JU AIRE funded project, started in 2009 and provided an initial platform to put RNP and 4DT together. With support from industry and the ANSP (LFV) the Swedish operator Novair conducted RNP CDA approaches into Stockholm Arlanda with Airbus 321s.

The aircraft was provided with NowCast uplinks and early approach assignments. An optimum trajectory was calculated by the Thales GE REL1A FMS2, and was flown with and without RTA constraint.

The RTA constraint was set at Flight Level 80 and both RTA performance and resulting ETA was studied. The aircraft met the time requirement with an average time accuracy of 8.6 seconds. The gains of efficiency and environmental impact during these flights was studied and quantified. The average fuel gain was 165kg and reduced CO₂ emissions of 518kg.

The importance of an improved AMAN to support these operations has been identified by both Eurocontrol and the AMAN provider, EGIS Avia with the MAESTRO AMAN. Eurocontrol has developed an AMAN – the TMA2010+ Concept Demonstrator (TCD), which fully integrates 4DT aircraft communication

and provides an efficient controller platform. EGIS Avia is participating in the MINT project and is gathering requirements on the future need for 4DT information in AMAN applications.

MAESTRO is installed in Sweden among other countries including South Africa.

Through these trials and demonstrations conducted with 4DT, CTA and RNP it has become evident that there are solutions available today to increase efficiency and reduce environmental impact.

The optimum trajectory

An optimum trajectory, or in SESAR terms the Reference Business Trajectory (RBT), should be defined as the optimum in terms of cost, efficiency and environmental impact. These often go hand in hand; when fuel consumption decreases so do emissions and cost. But they can also be contradictory such as for example increasing the flight path length on an RNP approach as to avoid noise sensitive areas. There is also a cost of time that is taken in account by using the FMS Cost Index. When the Cost Index is higher than zero, speed will increase as to gain time, resulting in increased consumption and thus emissions per NM.

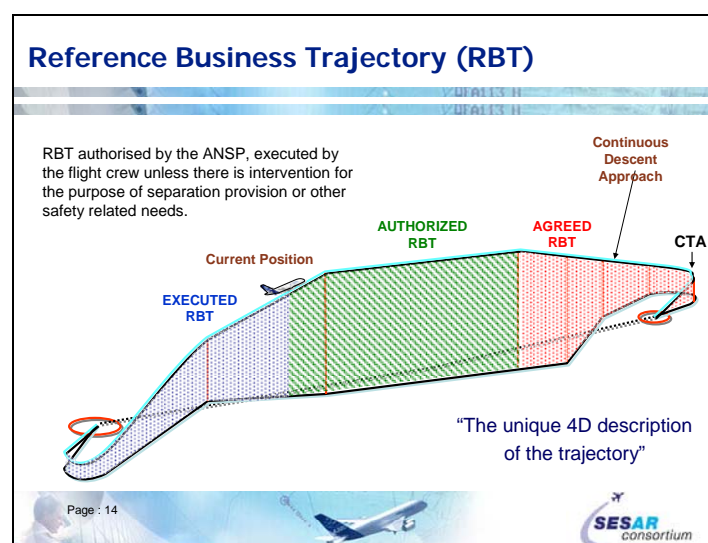


Figure 2 - RBT presented by SESAR JU.

The optimum trajectory starts naturally at the departure gate and ends at arrival. However, inefficiencies are today greatest in the approach segment and projects mentioned in this paper focus on this segment of the flight.

For the approach segment we can identify three dimensions of the trajectory that should be optimized:

- **Lateral.** The Lateral trajectory is straight-forward and the objective is to achieve the shortest route.
- **Vertical.** The vertical trajectory will be achieved through an optimum cruise altitude followed by an optimum descent. The trajectory should be free from vertical constraints that could impact the trajectory in a negative way. For a given aircraft type, the descent angle in idle descent will depend on optimum speed, Gross Weight etc.
- **Longitudinal.** The optimum longitudinal trajectory will be achieved with a speed equal to the optimum speed in cruise and descent.

The aircraft Flight Management System (FMS) will enable to follow the lateral track as well as calculate and follow a vertical and longitudinal trajectory:

- **Lateral.** The FMS will follow the lateral trajectory as defined, while calculating the vertical and longitudinal trajectory.
- **Vertical.** The optimum descent profile will be calculated by the FMS. The FMS will be provided with accurate wind and temperature information which is a prerequisite to fully optimize the trajectory.
- **Longitudinal.** The speed will depend on Cost Index. Speed corresponding to Cost Index 0 will give the speed of max specific range and therefore the speed of minimum emissions. A higher Cost Index will trade fuel for speed with the aim to reduce flying time. If a CTA is set, the objective will be, regardless of Cost Index to adapt

speed in cruise and descent as to meet the assigned CTA.

Efficiency

Efficiency can be defined either compared to baseline data or to an optimum calculated trajectory. AVTECH has developed the Efficiency Analyzer™ to assess the efficiency based on aircraft data¹¹.

In the analysis the first step is to isolate approach fuel consumption as defined by the consumption, from a geographical reference point to landing. The reference point will be chosen prior to TOD of the flights being studied. This is necessary in order to capture the entire value of the CDA and the improved trajectory.

A basic first Key Performance Indicator (KPI) can be established comparing standard approaches to baseline data. However, the flights will have a performance depending on four identified parameters:

- **Gross Weight**
- **Wind**
- **Temperature**
- **Altitude**

Normalization of data is therefore of interest as to give the possibility to assess performance from an individual flight. The AVTECH developed tool conducts this normalization and the normalized new KPI will reflect the gains if the flights had been flown in similar standard conditions.

Efficiency and environmental gains will be linked to the three dimensions previously mentioned:

- **Lateral.** Reduced track miles.
- **Vertical.** Continuous Descent Approach. On a given lateral path this descent will reduce the track miles at lower altitudes, where

¹¹ Data have been made available from standard Quick Access Recorder (QAR) and/or Digital ACMS Recorder (DAR) systems.

fuel consumption and emissions are high.

- **Longitudinal.** Optimum speed will be enabled, reducing fuel consumption and emissions.

In today's operation capacity issues are solved at the price of efficiency and environmental impacts through methods such as holding patterns and radar vectors. By reducing the use of these methods the efficiency and environmental impact gains to be found are important.

Prior to implementation, analysis of a conceptual approach can be conducted through simulations. In Figure 2 the

consumption and vertical profile for Arlanda Runway 26 can be seen.

The classic approach is in this case standard STAR followed by radar vectors and ILS. The radar vectored segment is a "good" radar vectored approach with a relatively short route and two level segments at FL130 and 5000ft QNH which is typically the case at Stockholm Arlanda. The consumption from the reference point to runway threshold is 488 kg.

The conceptual RNP approaches pass the same initial reference point and follow the FMS preferred vertical trajectory, ie. a CDA. The resulting consumption is 325 kg with a resulting efficiency gain of 163 kg.

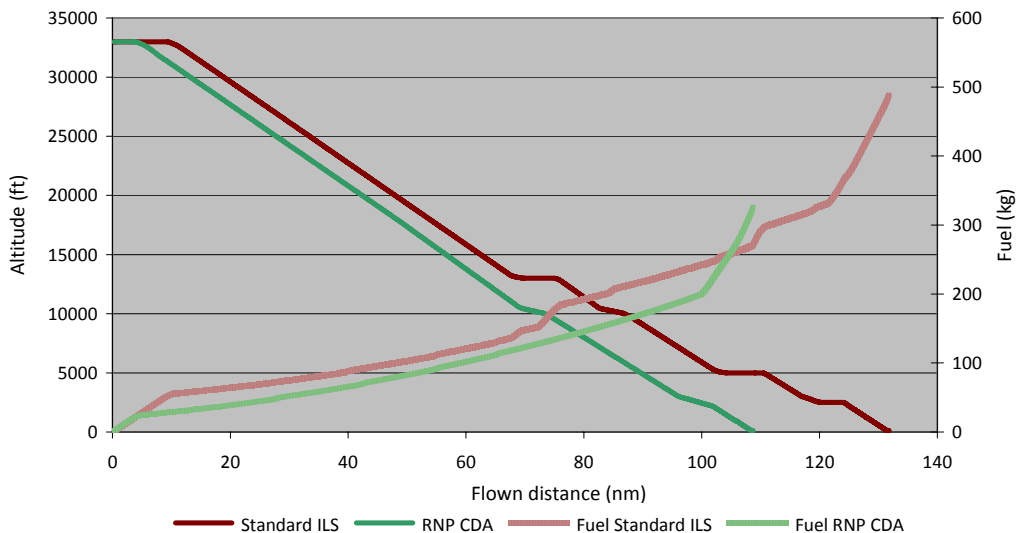


Figure 3 - Stockholm Arlanda. Conceptual vertical profile and fuel consumption of a single aisle aircraft, RNP vs ILS.

Environmental load

Green house gases are reduced with increased efficiency. A conventional aircraft engine emits 3.14 kg of CO₂ per kg of JET fuel burned. The reduced fuel consumption observed above can therefore be directly associated with a reduction of emitted green house gases. 163 kg of reduced consumption corresponds to 512 kg of reduced CO₂ emissions. NO_x emissions per unit of fuel depend on the engine technology and operating conditions.

Noise is also an environmental factor where PBO provides solutions. The following factors are of importance:

- **Idle CDA.** Engines at low thrust and a higher vertical profile results in lower noise.
- **Lateral track.** With RNP the lateral track can easily be controlled. Aircraft can avoid overflying noise sensitive areas and the lateral track can be placed over the best possible location. If several possible tracks exist these can be altered to reduce overall noise impact.

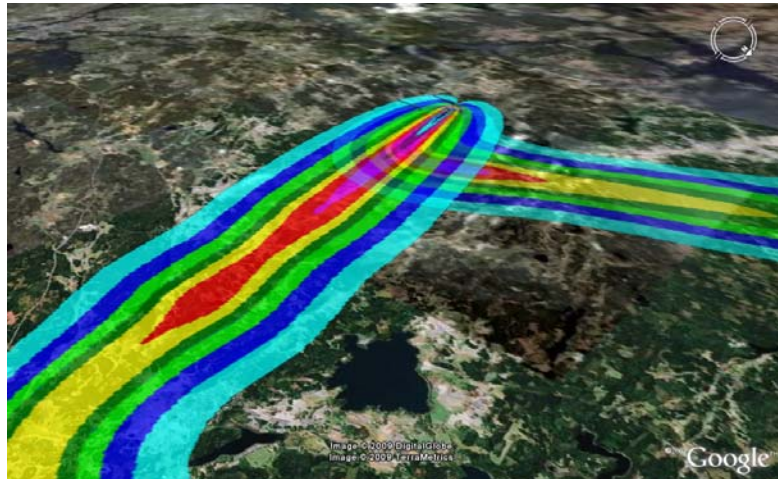


Figure 4 – Noise Arlanda Runway 26. ILS versus RNP.
AVTECH Noise Analyzer™ and Google Earth.

As can be seen in Figure 4, the noise is reduced. The red area corresponds to Noise over 75 dB and its size is reduced by 50%.

Capacity

An optimum trajectory provides extensive advantages in terms of efficiency and reduced environmental impact. However, capacity is a limiting factor for many airports. This is linked with PBO by the fact that an optimum trajectory has to be approved early, at least before leaving cruise altitude, typically 30 minutes before landing. Any modification of the trajectory after the Top of Descent (TOD) will inevitably result in inefficiencies.

If the trajectory and arrival time is of low importance, at low traffic, authorization can be granted without any direct control of arrival time. The aircraft will follow its preferred trajectory and land at an unpredicted and unplanned time.

If capacity is of importance there is a need, as for any logistical system, of planning. The controller needs a planning and a possibility to execute the planning, ie. control and sequence the traffic. By introducing an AMAN, CTA can efficiently

be assigned. This can be done for one or several aircraft on one or several trajectories. Depending on airspace the CTA can be assigned to runway threshold or any point before. Regardless of use of CTA or not, ETA can be monitored for any point.

The AMAN also provides a solution that ensures that the longitudinal trajectory is planned conflict free.

To maximize capacity CTA is used to lock aircraft into an arrival time. The theoretical total capacity exceeds 60 movements per hour in interleaving take off and landing mode.

The capacity in a time based system will depend on accuracy of arrival time. The AURORA project and the NUP2+ project have demonstrated that RTA performance is within seconds. In the logistical system of time based airport operations the aircraft can be efficiently flown within seconds to an entry point or runway threshold.

The AVTECH Runway Capacity Analyzer™ assumes the ETA or CTA as a value with a normal distribution at runway threshold. In Figure 5 capacity is expressed as a function of go around rate and normal distribution of CTA.

To ensure optimal capacity at the runway and in the TMA with the use of AMAN is a first step. In SESAR and

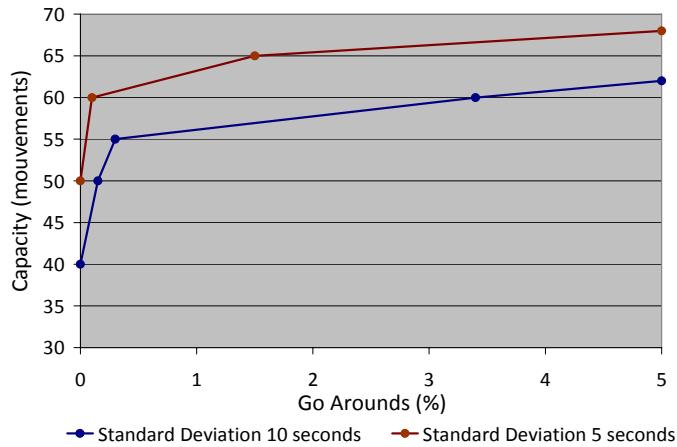


Figure 5 - Capacity Analysis.

Arrival times with Gaussian spread, standard deviation 5 sec and 10 sec. Interleaving take offs and landings. Runway Occupation Time (ROT): 46 sec (landing) and 50 sec (take-off).

NextGen capacity will be maximized, taking time based operations further. To achieve a fully optimized system strategic planning and sequencing is needed. This

will cover gate-to-gate operations. If for example flow control is needed at the arrival airport, the departure must be a function of the constraints of the arrival airport.

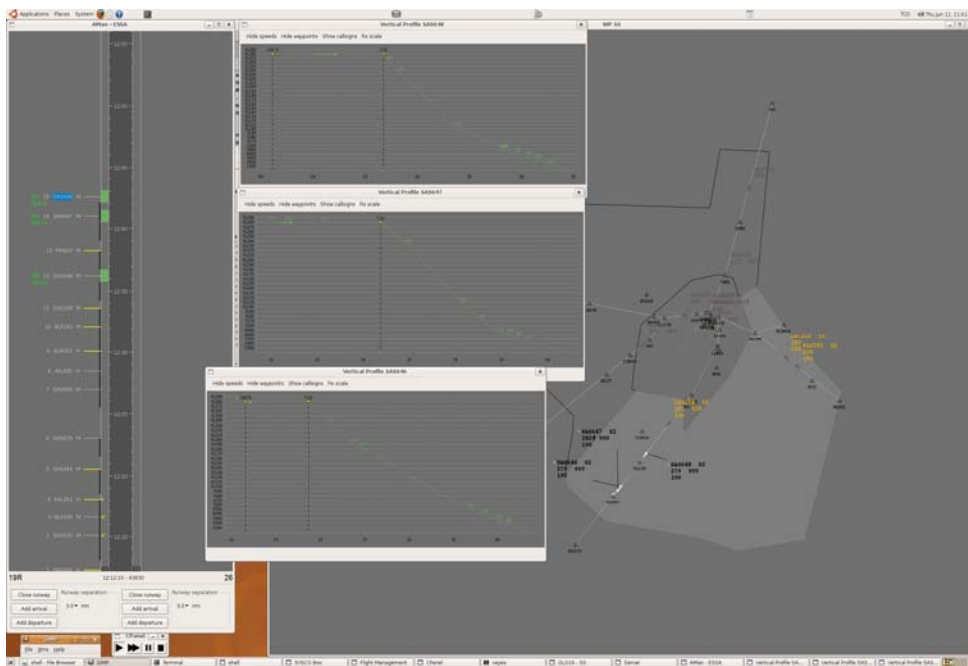


Figure 6 - Eurocontrol prototype AMAN - TCD developed under TMA 2010+. Three flights with RTA clearance into Stockholm Arlanda. Arrival sequence can be seen to the left with in green the RTA as well as the 1 min arrival slot. Lateral profile and three open windows with the vertical profile as predicted and communicated by the aircraft Flight Management System.



Figure 7 – Airbus A350 publicity spring 2009 promoting RTA and RNP. Other members of the Airbus fly-by-wire family also incorporate these functionalities.

Conclusion

In European, North American and Australian projects it has been demonstrated that airlines can operate more safely and efficiently with a reduced environmental impact.

Modern commercial aircraft have today the technology needed.

Manufacturers provide solutions for new aircrafts as well as solutions to upgrade the current fleet to adequate RNP capability. RTA functions, for improved air traffic flow control, are available at different levels of performance.

A prerequisite to implement PBO is to move together. The airline cannot alone implement PBO. Successful projects have been set up in collaboration with airlines, airports, ANSPs and regulatory authorities. Future PBO implementation will be founded on a solid common will to move ahead together.

It is clear that all will benefit from PBO. The airline has important safety and cost benefits. The airport and the community will enjoy benefits from reduced environmental impacts. The airports will be able to optimize their

efficiency in terms of handling etc. These benefits will be enabled while capacity is maintained or increased.

The ANSP's have the challenge to enable optimum operations. Planning will be the key to achieve this goal. Implementing efficient AMAN solutions to sequence optimum approaches will be a first step.

In this perspective, South Africa and Europe shares building blocks such as modern aircrafts as well as a Thales ATM system installed both in South Africa and in many European countries. The Thales ATM system incorporates the EGIS Avia AMAN system.

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